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National Laboratory

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# **Processing Meteorological Data for the CAP-88 PC Model at Los Alamos National Laboratory**

Authors: Kenneth Waight and David Bruggeman, EPC-CP

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## ACRONYMS AND ABBREVIATIONS

CAP-88	Clean Air Act Assessment Package 1988
CFR	Code of Federal Regulations
EPA	Environmental Protection Agency
EPC-CP	Environmental Protection and Compliance-Compliance Programs
LANL	Los Alamos National Laboratory
NESHAP	National Emission Standards for Hazardous Air Pollutants
NWS	National Weather Service
P-G	Pasquill-Gifford stability categorization system
PV-WAVE	Precision Visuals – Workstation Analysis and Visualization Environment
STAR	Stability ARray
TA	Technical Area

## 1.0 BACKGROUND

The Environmental Protection and Compliance-Compliance Programs (EPC-CP) group at Los Alamos National Laboratory (LANL) uses the Clean Air Act Assessment Package 1988 (CAP-88, Littleton 2020) PC model (Version 4.1) to estimate radiological doses for a set of areal sectors surrounding a release location, in order to satisfy the Environmental Protection Agency (EPA) National Emission Standards for Hazardous Air Pollutants (NESHAP) dose calculation requirement in 40 CFR 61 Subpart H. Among several types of data that must be prepared for CAP-88 input is a text file of meteorological data (“WIND” file), consisting of the joint frequency of wind direction, wind speed, and atmospheric stability categories.

EPC-CP produces customized WIND files by running a CAP-88 utility program on a user-generated text file of wind data in a different format, known as a STability ARray (STAR) file (Turner, 1964). At LANL, EPC-CP meteorologists prepare customized STAR files with data over desired time periods at selected meteorological towers. A custom program written in Precision Visuals – Workstation Analysis and Visualization Environment (PV-WAVE), a commercial Fortran-like language, is used to read LANL meteorological data and write a STAR file; the executable filename is “Star.out”. However, the outdated PV-WAVE utility program is being phased out by EPC-CP, due to the inefficient process to run it and an inability to modify the code.

To preserve the ability to create customized meteorological data for CAP-88 in a way that will be easy to use and maintain, a new replacement utility program, written in the Python programming language, has been developed. The new, improved program reads a data file from any LANL meteorological tower, and at each desired observation time, determines the wind direction, wind speed, and stability categories defined in the CAP-88 documentation. The frequencies of all combinations of the three sets of categories are calculated and written to a file in the STAR format, which can later be converted to a WIND file for input into CAP-88.

The following sections describe the new process for developing customized meteorological data for input to CAP-88 PC.

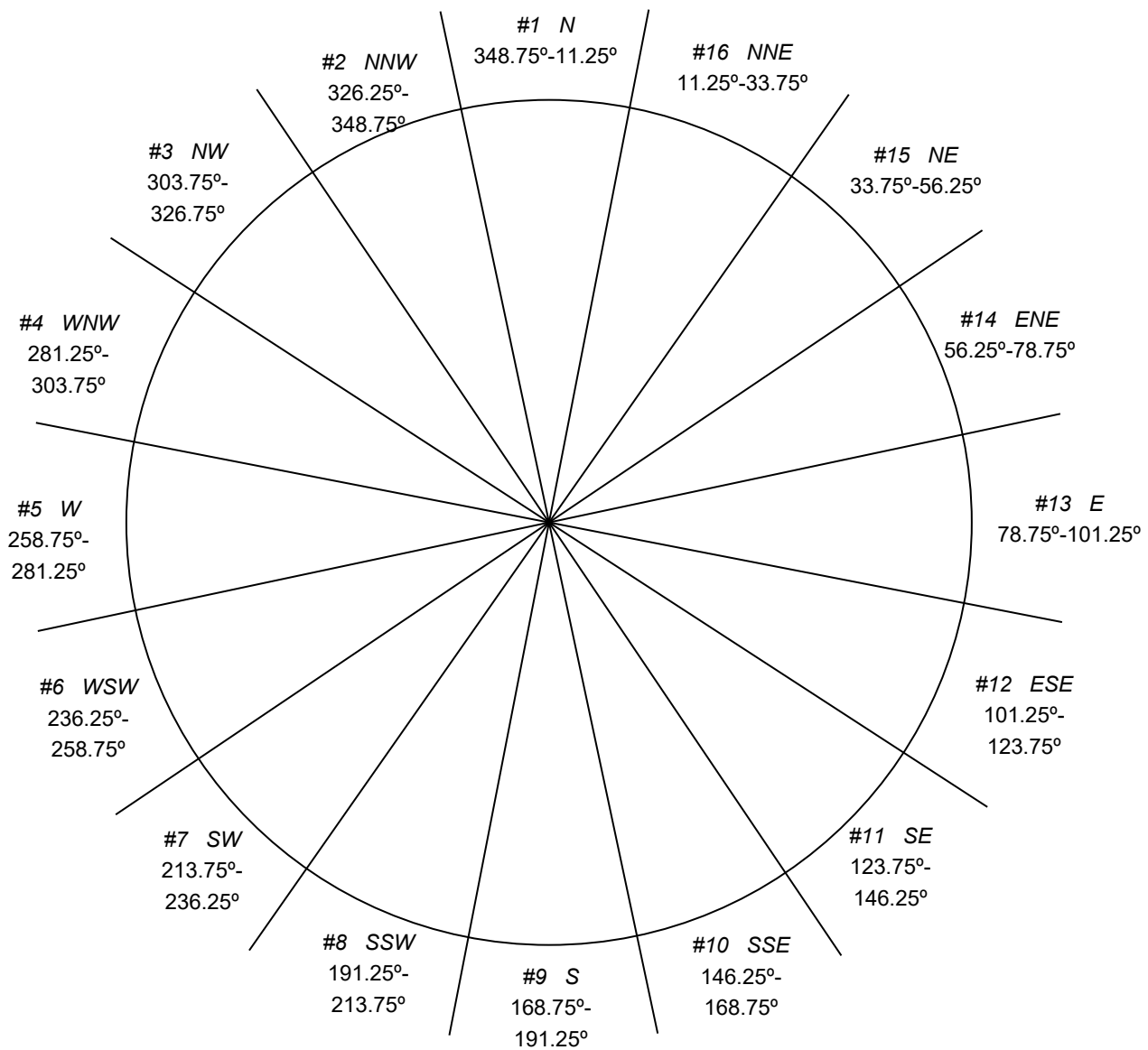
## 2.0 CATEGORIZATION OF WIND DIRECTION, WIND SPEED, AND STABILITY

For each observation time in a selected period, near-surface LANL meteorological data is used to select the correct category for wind direction, wind speed, and stability, the three inputs needed to perform a CAP-88 calculation. The standard level for near-surface wind observations is 10 m above the ground, which is used by the National Weather Service (NWS) at its first-order weather stations. However, all of the tall LANL meteorological towers have the lowest observation level at 11.5 m (often listed as 12 m).

While reviewing EPA-454/R-99-005, *Meteorological Monitoring Guidance for Regulatory Modeling Applications* (EPA 2000), it was determined that the PV-WAVE code deviated from EPA guidance in some ways. The following subsections examine each meteorological variable and show how each of the issues is resolved.

### 2.1 Wind Direction Categories

CAP-88 defines sixteen wind direction sectors, each covering a range of 22.5 degrees azimuth centered on one of the 16 cardinal compass points, as shown in Fig. 2-1. It follows the meteorological convention of defining wind direction as the direction from which the wind is blowing. Each wind direction observation is placed into one of these 16 categories. The treatment of wind direction is the same for the PV-WAVE code and the new code.



**Figure 2-1: Wind direction categories for CAP-88**

## 2.2 Wind Speed Categories

Although CAP-88-PC Version 4.1 (Littleton, 2020) allows the user to customize wind speed categories, EPC-CP plans to continue using the original set of wind speed categories, defined in the CAP-88 documentation of the STAR file format. There are six (6) wind speed categories, with speeds in units of nautical miles per hour (knots). These are: 1-3, 4-6, 7-10, 11-16, 17-21, and greater than 21 knots. That classification is coarse and not sufficiently explicit, since the observed values are in tenths of meters per second ( $\text{m s}^{-1}$ ) rather than

integer knots. There are different ways that the knot ranges could be translated into  $\text{m s}^{-1}$  ranges, but nowhere in the CAP-88 documentation (through several versions of the model) are a set of endpoints defined to clearly delineate the categories. However, documentation of a recent utility program to convert a STAR file into a WIND file (EPA 2019) includes a table that reveals the average wind speeds for each category, which are shown in Table 2-1.

**Table 2-1: Average wind speeds for the six original wind speed categories in CAP-88**

Wind Speed Category	Average Wind Speed ( $\text{m s}^{-1}$ )
1	0.772
2	2.572
3	4.373
4	6.945
5	9.774
6	11.83

The PV-WAVE program uses the set of wind speed ranges in Table 2-2, and the resulting average wind speeds (averages of the low and high values of the ranges) for the same six wind speed categories. The highest category does not have an average wind speed because it includes any values above the lower threshold. These are quite close to the averages from the CAP-88 documentation (EPA 2019) in Table 2-1.

**Table 2-2: Wind speed categories used in the obsolete PV-WAVE code**

Wind Speed Category	Wind speed ( $\text{m s}^{-1}$ )	Average wind speed ( $\text{m s}^{-1}$ )
1	$0 \leq \text{speed} < 1.56$	0.78
2	$1.56 \leq \text{speed} < 3.35$	2.455
3	$3.35 \leq \text{speed} < 5.59$	4.47
4	$5.59 \leq \text{speed} < 8.27$	6.93
5	$8.27 \leq \text{speed} < 10.95$	9.61
6	$10.95 \leq \text{speed}$	--

However, the PV-WAVE wind speed ranges differ more significantly from another set of wind speed ranges in LANL Technical Procedure EPC-ES-TP-501, *Dose Assessment Using CAP-88* (Mcnaughton 2018). But since the CAP-88 documentation is not explicit enough and previous CAP-88 work by EPC-CP has consistently used the PV-WAVE categories over the years, there is no compelling reason to adopt the different set of wind speed categories in EPC-ES-TP-501. Accordingly, it was determined that the new utility code will continue to use the PV-WAVE wind speed categories.

Since wind speed in the planetary boundary layer generally increases with height due to decreasing friction with the Earth's surface, directly using wind speeds measured at 11.5 m instead of the wind speeds at the expected standard height of 10 m would result in a small high bias of frequencies in the higher wind speed categories. To rectify this, the logarithmic wind profile technique in EPA (2000) is applied to convert the measured 11.5 m wind speeds to inferred speeds at 10 m. EPA guidance provides a set of coefficients for the

traditional power law wind speed profile as a function of stability category, which allows a simple estimation of the wind speed at 10 m using the following equation:

$$u_z = u_r \left( \frac{Z}{Z_r} \right)^p$$

where  $u_z$  is the wind speed at level  $Z$ ,  $u_r$  is the wind speed at a reference level  $Z_r$ , and  $p$  is the power law exponent for a given stability category and terrain type. For this application,  $u_z$  is the wind speed at 10 m,  $u_r$  is the wind speed at 11.5 m,  $Z$  is 10 m and  $Z_r$  is 11.5 m.

EPA (2000) guidance includes  $p$  exponent values for both urban and rural morphologies. The rural coefficients (Table 2-3) should be more appropriate for LANL and will always be used.

**Table 2-3: Power law wind speed profile exponents for each P-G stability category**

Stability Category	$p$ Exponent (Rural)
A	0.07
B	0.07
C	0.10
D	0.15
E	0.35
F	0.55

For each observation time, the 10 m wind speed is estimated using the power law wind profile, after the stability category is determined (See Section 2.3) to determine the appropriate power law exponent. The calculated 10 m wind speeds are then categorized and used for the STAR file.

It should be emphasized that the reduction in wind speed is generally quite small. An observed 11.5 m wind speed of  $10 \text{ m s}^{-1}$  is reduced to  $9.90 \text{ m s}^{-1}$  at 10 m for the least stable category, or to  $9.26 \text{ m s}^{-1}$  for the most stable category. However, the slightly lower wind speeds can have a significant effect, as one CAP-88 test run showed a 5% increase in dose caused by the change. This justifies the process of converting the wind speeds to the standard measurement level. Each converted wind speed is placed into one of the six wind speed categories.

## 2.3 Stability Categories

As with many other Gaussian atmospheric dispersion models, CAP-88 uses a set of Pasquill-Gifford (P-G) stability categories (Pasquill 1961, Turner 1964, Turner 1997, EPA 2000) to characterize the turbulence in the lower atmosphere, as follows:

- Stability Category A = Extremely Unstable
- Stability Category B = Moderately Unstable
- Stability Category C = Slightly Unstable
- Stability Category D = Neutral
- Stability Category E = Slightly Stable
- Stability Category F = Moderately Stable

An additional stability category (G = Extremely Stable) is not commonly used at DOE facilities.

EPA (2000) discusses several possible ways of calculating the P-G stability category, depending on which types of near-surface data are available. LANL meteorological tower measurements include high-quality data, and the magnitude of the vertical standard deviation of the elevation angle of the wind ( $\sigma_E$ ) is used to infer the stability category (the “ $\sigma_E$  method”). The magnitude of fluctuations in vertical velocity are correlated with vertical stability, where larger fluctuations indicate more unstable conditions. Table 2-4 shows how values of  $\sigma_E$  are empirically mapped to stability categories (Table 6-8a in EPA 2000).

**Table 2-4. Stability Category Based on Elevation Angle Turbulence Measurements (EPA-454/R-99-005)**

<b>P-G Stability Category</b>	<b>Standard Deviation of Wind Elevation Angle (<math>\sigma_E</math>)</b>
A	$11.5^\circ \leq \sigma_E$
B	$10.0^\circ \leq \sigma_E < 11.5^\circ$
C	$7.8^\circ \leq \sigma_E < 10.0^\circ$
D	$5.0^\circ \leq \sigma_E < 7.8^\circ$
E	$2.4^\circ \leq \sigma_E < 5.0^\circ$
F	$\sigma_E < 2.4^\circ$

Both the PV-WAVE program and Technical Procedure EPC-ES-TP-501 use this approach, but neither completely implements the EPA 2000 algorithm. After some deliberation, it was decided that the new program should closely follow the EPA 2000 guidance, which is presented below.

The standard deviation of the elevation angle of the wind is calculated from  $\sigma_w$ , the standard deviation of the measured vertical velocity, using the following equation:

$$\sigma_E = \frac{\sigma_w}{u}$$

where  $u$  is the average wind speed.  $\sigma_E$  from this equation is in units of radians, which is multiplied by  $180/\pi$  to convert to degrees azimuth. Then an initial estimate of the P-G category is made based only on ranges of  $\sigma_E$  values.

Importantly though, EPA 2000 describes two adjustments that may need to be made to the ranges of  $\sigma_E$  values in Table 2-4, and both of them should be used for the application of this methodology at LANL.

**Roughness Length Adjustment:** The ranges of  $\sigma_E$  values need to be adjusted for a roughness length that differs from the EPA-assumed value of 15 cm. The ranges of  $\sigma_E$  values are multiplied by the following factor:

$$\left(\frac{z_0}{15}\right)^{0.2}$$

where  $z_0$  is the roughness length of the local site in centimeters. Bowen (1990) estimated a roughness value for LANL as 38 cm at one location (TA-50), and another study (LANL 2017) found a fairly large range of roughness values at various LANL locations, from 18 to 61 cm, shown in Table 2-5.

**Table 2-5. Facility-Specific Roughness Lengths**

LANL Facility	Legacy Average Roughness Length (cm)	Revised Roughness Length (cm)	Meteorology Tower Basis
Area G	38	18	TA-54
CMR	40	41	TA-06
NES	40	25	TA-53
PF-4	40	35	TA-06
RANT	38	23	TA-54
RLWTF	38	35	TA-06
TWF	38	36	TA-06
WCRRF	38	35	TA-06
WETF	100	61	TA-06/TA-49

To determine whether a single lab-wide value for roughness length would be sufficient for CAP-88 applications, several sensitivity tests were performed to determine how much the adjustment of stability category criteria for roughness length would affect CAP-88 results. Increasing (decreasing) the assumed roughness length has the effect of modestly shifting the distribution of stability categories toward the more stable (less stable) categories. The test results showed that doubling the roughness length increased the highest dose in one CAP-88 run by 3-6%, presumably because a greater frequency of more stable categories causes the code to assume less vertical mixing of the plume. This effect is modest but could be significant in some situations.

A decision was made to set a default roughness value of 40 cm as a reasonably representative and conservative (erring on the side of a higher dose) estimate of roughness length for LANL. However, the code allows the specification of a custom roughness length to override the default, when desired.

**Wind Measurement Height Adjustment:** The second possible change to the  $\sigma_E$  ranges is to adjust for a wind measurement height that differs from the standard 10 m level, as was done for the wind speed categories. The TA-5 Mortandad Canyon tower measures winds at the 10 m level, and the three new towers that are soon to be operational (TA-16B, TA-54B and TA-63) will also measure winds at the standard height. However, the four taller towers

(TA-06, TA-49, TA-53 and TA-54) have their lowest wind measurements at 11.5 m. The adjustment is made by multiplying the lower value of each  $\sigma_E$  range by the following equation:

$$\left(\frac{Z}{10}\right)^{P_\phi}$$

where  $Z$  is the non-standard wind measurement height in meters and  $P_\phi$  is a function of the P-G stability category, as shown in Table 2-6.

**Table 2-6: Adjustment coefficients for each P-G stability category to account for a non-standard wind measurement height**

Stability Category	$P_\phi$
A	0.02
B	0.04
C	0.01
D	-0.14
E	-0.31

The lower value in one range is the higher value in the adjacent range. No coefficient is needed for stability category F, because the lower bound of the range is zero. These adjustments are small in magnitude. For example, at a height of 11.5 m and a P-G category of D (neutral), an adjustment factor of 0.98 results.

Applying both the roughness length and wind measurement height adjustments to the original EPA categories (Table 2-4) produces the initial classification in Table 2-7.

**Table 2-7: Example of P-G stability categories assumed from vertical turbulence measurements, adjusted for both a non-standard wind measurement height (11.5 m) and a representative lab-wide surface roughness of 40 cm**

Initial Stability Category	$\sigma_E$ range (degrees)
A	$14.0 \leq \sigma_E$
B	$12.2 \leq \sigma_E < 14.0$
C	$9.5 \leq \sigma_E < 12.2$
D	$6.0 \leq \sigma_E < 9.5$
E	$2.8 \leq \sigma_E < 6.0$
F	$\sigma_E < 2.8$

Different choices for roughness length and/or wind measurement height when running the program would slightly modify the values.

The final step in the EPA-prescribed process for stability categorization is to determine the final category, depending on the initial category, the time of day and the wind speed. Downward solar irradiance data is used to determine whether it is day or night, with an irradiance value greater than or equal to a threshold value of  $5 \text{ W m}^{-2}$  indicating daytime. Table 2-8 shows the adjustment for daytime, and Table 2-9 for nighttime, both reproduced from Table 6-8b in EPA (2000).

**Table 2-8: Daytime criteria for possible changes of P-G stability categories**

Initial Category	wind speed (m s <sup>-1</sup> )	Final Category
A	$u < 3$	A
A	$3 \leq u < 4$	B
A	$4 \leq u < 6$	C
A	$6 \leq u$	D
B	$u < 4$	B
B	$4 \leq u < 6$	C
B	$6 \leq u$	D
C	$u < 6$	C
C	$6 \leq u$	D
D, E, or F	Any	D

**Table 2-9: Nighttime criteria for possible changes of P-G stability categories**

Initial Category	10 m wind speed (m s <sup>-1</sup> )	Final Category
A, B, C or D	Any	D
E	$u < 5$	E
E	$5 \leq u$	D
F	$u < 3$	F
F	$3 \leq u < 5$	E
F	$5 \leq u$	D

The effect of these changes is to shift the data distributions toward neutral stability for higher wind speeds, and to change the distributions to neutral stability when observations differ from the expected daytime (unstable) and nighttime (stable) conditions. The resulting final stability category is then added to the wind direction and wind speed categories.

After all adjustments are made, the observation is placed into one of the 6 stability categories.

### 3.0 WRITING A STAR FILE WITH TOWER2STAR.PY

Since PV-WAVE will be phased out, a new program, tower2star.py, was written in the Python language to read LANL meteorological data and write a STAR file, which can then be converted to a WIND file for input to CAP-88. The STAR file format is described in Littleton (2020). The Appendix below shows the arguments and options used for the new program, and an example of its output.

For each observation time, the program checks that all of the required variables are present and have reasonable values of the required meteorological data that includes wind direction, wind speed, standard deviation of vertical velocity at level 1 (10 m or 11.5 m for LANL towers), and shortwave irradiance. Then the wind direction, wind speed, and stability categories are determined, and the observation time is accounted for by incrementing a count by one for that combination of categories. After all desired observation times have been processed, frequencies are calculated by dividing the count for each category combination by the total number of observation times processed.

Here is an example of the first few lines of a resulting STAR file.

```
NNE A 0.001530.000610.000000.000000.000000.000000
NE A 0.002590.001390.000000.000000.000000.000000
ENE A 0.004500.001780.000000.000000.000000.000000
E A 0.004720.002580.000000.000000.000000.000000
ESE A 0.003880.002270.000000.000000.000000.000000
SE A 0.002900.002170.000000.000000.000000.000000
SSE A 0.002190.002120.000000.000000.000000.000000
S A 0.001450.001090.000000.000000.000000.000000
SSW A 0.000850.000890.000000.000000.000000.000000
SW A 0.000700.000360.000000.000000.000000.000000
WSW A 0.000490.000280.000000.000000.000000.000000
W A 0.000370.000250.000000.000000.000000.000000
WNW A 0.000320.000350.000000.000000.000000.000000
NW A 0.000500.000400.000000.000000.000000.000000
NNW A 0.000540.000250.000000.000000.000000.000000
N B 0.000270.000250.000030.000000.000000.000000
NNE B 0.000420.000710.000010.000000.000000.000000
. .
. .
```

The first line shows frequencies for the NNE (north-northeast) wind direction category and stability category A. The six values represent the frequency of observation times in the six wind speed categories for that wind direction and stability category combination. The lowest wind speed category, with speeds below  $1.56 \text{ m s}^{-1}$ , has a frequency of 0.00153, or 0.153%, meaning that only 0.153% of all observation times simultaneously had a wind direction from NNE, a P-G category of A (very unstable), and a wind speed below  $1.56 \text{ m s}^{-1}$ . The next higher wind speed category has a frequency of 0.00061, or 0.061%, and so forth.

When a CAP-88 user requests data from a particular LANL meteorological tower and for a specified period, an EPC-CP meteorologist retrieves a 15-minute data file for the desired time period and runs the tower2star.py program, passing the resulting STAR file back to the CAP-88 user. The new program has options to select only day or night observation times, or

to select only data for a given month. For example, running the program with 5 years of 15-minute meteorological data could produce a STAR file reflecting all of the observation times in the entire period, or only the times during the day or night, or only the September times, or only daylight times during September.

The user could also specify a desired roughness length, different than the 40 cm default value for LANL, and/or a wind measurement height, which may be different than the 10 m default. For the LANL tall towers, the wind measurement height argument should be set to 11.5.

## 4.0 COMPARISON OF TOWER2STAR.PY AND PV-WAVE OUTPUT

In order to understand the effect of the changes that were made in the new tower2star.py code, tests were made to compare STAR files produced by the new program to those produced by the previous PV-WAVE code. In each case, the new program was tested with the default 40 cm roughness length, and by specifying the measurement height of 11.5 m instead of the 10 m default. Another script was written to compare the frequencies in all of the wind direction/wind speed/stability categories between two STAR files. Results were compared for three different scenarios:

1. STAR files were produced with 15-minute data from the TA-6 tower for all of 2018. The mean absolute frequency difference was 0.02%, the RMS (root mean square) difference was 0.08%, and the largest difference in any category was 0.8%.
2. The same comparison was made using data from TA-49 for all of 2017, but only daytime observations were used (CAP-88 users sometimes request STAR files for only the daytime period). The mean absolute frequency difference was 0.01%, the RMS difference was 0.04%, and the largest difference in any category was 0.4%.
3. The final comparison used data from TA-54 for 2014-2018, but only times in September (so five years of Septembers). The mean absolute frequency difference was 0.04%, the RMS difference was 0.14%, and the largest difference in any category was 1.3%.

All of these differences are quite small, considering the various improvements in the new program, such as the increased complexity of the stability class determination, and the adjustment of wind speeds from 11.5 to 10 m. Therefore, the new program will be used for all new CAP88 work.

## **5.0 SUMMARY**

A new utility program was developed to prepare LANL meteorological data for input to the CAP-88 PC model, to replace a previous outdated program that could no longer be maintained.

Differences between the previous program and the guiding EPA documentation were resolved, and decisions made to modify the algorithms to more completely conform to the EPA documentation, where possible, and to retain the previous method when the documentation was not definitive enough. The major changes are that the new program: (1) uses the complete EPA method to calculate the stability category; (2) optionally estimates the wind speed at the standard 10 meter level from observations at non-standard levels; and (3) allows the specification of a surface roughness height appropriate for the observation location.

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## APPENDIX

### Options for tower2star.py

```
usage: tower2star.py [-h] [-v] [-raw] [-z0 ROUGHNESS] [-windheight WINDHEIGHT]
                    [-noestimate10m] [-day | -night] [-mon MONTH]
                    [-o STARFILE]
                    metfile
```

Read a Weather Machine file and produce a CAP88 STAR file, data.str

positional arguments:

metfile                      Name of met file to read

optional arguments:

```
-h, --help                      show this help message and exit
-v, --verbosity                Increase the verbosity of the output
-r, --raw, --datalogger        File is in the raw met format (from the datalogger)
-z0 ROUGHNESS, --roughness ROUGHNESS
                               Roughness length (cm), used for stability
                               determination
-windheight WINDHEIGHT, --windheight WINDHEIGHT
                               Wind measurement height, used for stability
                               determination if it's not the 10 m default
-noestimate10m, --noestimate10m
                               Do not estimate the wind speed at 10m from a non-
                               standard height
-day, --day                    Use only daytime data
-night, --night                Use only nighttime data
-mon MONTH, --month MONTH
                               Use data from any year but only a single specified
                               month (1-12)
-o STARFILE, --starfile STARFILE
                               Alternate name of the CAP88 STAR file that will be
                               written
```

## Example of tower2star.py Output

The following output is the result of the command:

```
python tower2star.py -windheight 11.5 -day TA6_15_2019.csv
```

```
=====
Creation of a STAR file for CAP88
=====
```

```
Roughness length (z0) used to adjust stability category determination: 40.0
```

```
Non-standard wind measurement height (not 10 m) used to adjust stability category
determination: 11.5
```

```
Final wind speeds will be estimated at 10 m from power law.
```

```
Reading LANL file: TA6_15_2019.csv
```

```
Build list of all possible 15 min times
```

```
Calculate how much data is being used for each year:
    2019  50.2% of possible 15 min times is being used
```

```
-----
Summary of data found
-----
```

```
35040 total possible 15 min times over the period of the data file.
35040 times with data found, 100.00% of possible
0 duplicate times found, 0.00% of found times
426 times with flagged data skipped, 1.22% of found times
1 times with bad/out of range data, 0.00% of found times
17017 times ignored (wrong time of day or month), 48.56% of found times
17596 times used to create STAR file, 50.22% of found times
```

```
-----
Calculate frequencies for each combination of wind direction/stability class/wind
speed:
-----
```

```
Total sum of all frequencies after rounding to 5 digits: 0.99998
```

```
Simple depiction of frequencies:
    (single digits are % of total, . is < 1%, + is >= 10%)
```

```
Stability Class: A
```

```
-----
N   |..   |
NNE |..   |
```

NE	..	
ENE	1.	
E	1.	
ESE	1.	
SE	1.	
SSE	..	
S	..	
SSW	..	
SW	..	
WSW	..	
W	..	
WNW	..	
NW	..	
NNW	..	

-----

Stability Class: B

-----

N	...	
NNE	..	
NE	..	
ENE	..	
E	..	
ESE	..	
SE	..	
SSE	..	
S	..	
SSW	..	
SW	..	
WSW	.	
W	...	
WNW	...	
NW	...	
NNW	...	

-----

Stability Class: C

-----

N	...	
NNE	...	
NE	.1.	
ENE	.1.	
E	.1.	
ESE	.1	
SE	.1.	
SSE	.2.	
S	.1.	
SSW	....	
SW	...	

```
WSW |.... |
W   |.... |
WNW |...  |
NW  |.... |
NNW |...  |
-----
```

Stability Class: D

```
-----
N   |.1... |
NNE |121.  |
NE  |11..  |
ENE |11.   |
E   |11.   |
ESE |11..  |
SE  |121.  |
SSE |142.  |
S   |1461. |
SSW |1341..|
SW  |.231..|
WSW |1121..|
W   |.231..|
WNW |.221..|
NW  |.111. |
NNW |.1...  |
-----
```

Stability Class: E

```
-----
N   |      |
NNE |      |
NE  |      |
ENE |      |
E   |      |
ESE |      |
SE  |      |
SSE |      |
S   |      |
SSW |      |
SW  |      |
WSW |      |
W   |      |
WNW |      |
NW  |      |
NNW |      |
-----
```

Stability Class: F

```
-----
```

N		
NNE		
NE		
ENE		
E		
ESE		
SE		
SSE		
S		
SSW		
SW		
WSW		
W		
WNW		
NW		
NNW		

-----

Writing to STAR file: data.str

-----

Summary

-----

tower2star.py -windheight 11.5 -day TA6\_15\_2019.csv

Met input data file: TA6\_15\_2019.csv

Used only daytime data

Assumed default roughness of 40.0 cm

Used custom wind measurement height of 11.5 m

Final wind speeds were estimated at 10 m from power law

Output file written with the generic name: data.str

tower2star.py completed.